The Criteria for Choosing the Optimal Solution Under the Uncertainty in Project Management

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Abstract
Thoughtful, well-organized cooperation of specialists in intersectoral projects has an undoubted synergetic effect. At the same time, the support of such a complex project involves the thorough involvement of business analysts. To model the process of selecting additional functions of the information technology, it is convenient to use Petri nets to visualize both parallel and sequential processes. The use of methods of expert evaluation, decision-making, decision-making under uncertainty to support the work of business analysts will allow taking into account various criteria of such intersectoral cooperation. As a criteria of decision-making under uncertainty, the Laplace, Wald, Bayes, Hermeyer, Savage, Hurwitz, Khodg-Lehmann criteria were analyzed, as well as the criteria of extreme optimism, extreme pessimism, compromise criterion, and product criterion.
Keywords [1]
Project management, decision under uncertainty, business process, business analyst, Petri nets, analytic hierarchy process, AHP

1 Introduction

The pandemic influenced different spheres of our life. Fighting the damages it caused in medicine, economics, psychology, education, wellbeing, etc., we must not concentrate on negative consequences only, but on the very reasons why our society was not ready for such cataclysm. Humanity is forced to reconsider the management in such almost canonical processes as education, science, medicine, etc. Public administration should shift the focus from managing each direction separately to complex vision, and convert sporadic practices of intersectoral projects on the state level into solid politics of interconnectional development, thoroughly planned and planned as such from the very beginning of the cooperation [1-8]. No doubt, that information technologies should be the mean – basic and powerful – of such intersectoral cooperation.

It seems convenient to explain the benefits and difficulties of such top-level intersectoral project management on the example of education of disabled students. The very beginning of such cooperation is on the stage of assessment of the psychophysical conditions of a child. In Ukraine, it is a duty of state health institution, which is called *Psychological, Medical, and Pedagogical Committee* (here and after, PMP Committee). The specialists of such committee should perform the psychophysical diagnostics of a child, make a conclusion about its condition, suggest a form of education (normal, inclusive, special), develop a treatment strategy (if needed) [9]. Until recently, the only information technology that supported the activity of the PMP Committee was a website with basic information on working hours, staff, general information on various disabilities. The internal medical documentation was in paper. Before 2020, creating an information technology to automate internal document flow in PMP Committee seemed to be an actual practical task, but it is not

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anymore. To support the processes in PMP Committee now, it is crucial to involve representatives from different branches [9], that are involved in processes of support of disabled persons` lifelong wellbeing.

Traditionally, designing a health care institution management software, developers are led by state standards and protocols of health care. As input data, such software needs patient ID, screening and diagnosing results, etc. These data are saved, can be looked through, and printed out in a form of a history of a disease. To order such software (an information technology, actually), in Ukraine, the public health care organization should use an open electronic system of public procurement *ProZorro* (https://prozorro.gov.ua/). This resource is an online platform where state and municipal customers announce tenders for the purchase of goods, works, and services, and business representatives compete in tenders for the opportunity to supply it to the state. From the point of view of the PMP Committee needs, in such a way the state could have ensured the cooperation between the state health care organization and IT company. But such cooperation between these three subjects is rather narrowly focused from the side of the state, at least. Such cooperation is rather limited in its variations: the state health organization gets the IT to automate some processes, and the state pays for it. But this fact can be changed by adding one more facet to such cooperation, i.e. the scientific approach. In fig 1, there’s a concept of such cooperation, enriched with possibilities that enable an application of data science to the cooperation of IT, state, and medicine.

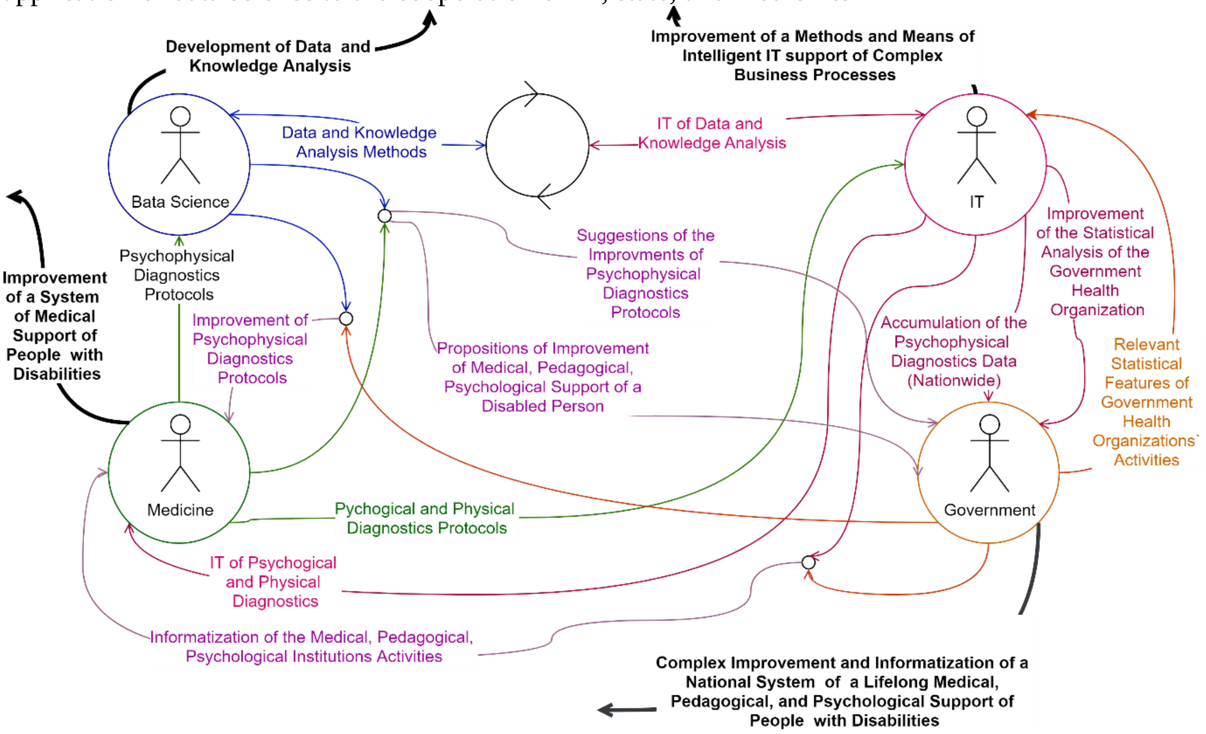

Figure 1. The concept of cooperation between Data Science, IT, state, and medicine

To achieve the synergetic effect from such cooperation, it should be well organized. On the opposite of the traditional order of IT development which ends with the IT implementation, the proposed scheme foresees constant cooperation and constant improvement of the outcome (black-colored edges). By participating in such cooperation, the IT company/ies should provide the project managers of such complex process, and involve business analyst (or a group of one) to control a lot of business processes. It is worth mentioning that the business process is understood as one that enables some profit, expressed in money or time savings (any other kind of profit can be measured in time or money units, as well). The main goal of this research is to suggest an approach to the management of the projects, which should result in an IT that has two layers of functions, i.e. functions that should be realized unconditionally, and functions that are additional, and the very set of the functions, the sequence of its realization, and their effectiveness may vary. If we go back to the example of PMP Committee example, the must-have function of the IT, developed to automate the processes in the

Committee, are those that enable the document flow according to state health care standards. The additional functions are those that can the PMP Committee specialists suggest with their experience of working with disabled children, and, of course, those functions that might suggest the data analysts, according to diagnostics results they would be provided [10], [11]. For example, some data science methods can analyze, which diagnosing procedures can be odd, and the decision on the diagnosis can be made on less number of characteristics of a child.

2 Modeling the process of selecting additional functions

Let us recall that during the intersectoral cooperation, mentioned above, demands that the developed information technology should unconditionally have basic functions, realized according to state standards. The list of additional functions can be formed during a cooperation between all participants. Additional functionality of such information technology might be, for example, the following.

- Availability of methods of data and knowledge analysis extraction based on existing results of psychophysical diagnostics.
- Availability of methods of data and knowledge analysis, based on which it is advisable to update the protocol of psychophysical diagnosis.
- Automation of the PMP Committee activity.
- Development of a national system for consolidating the results of psychophysical diagnosis;
- Adaptation of IT to the national system of support for lifelong learning.
- Automate compliance with IT requirements used by people with special needs, etc.

Collaborators mentioned in Fig.1, can evaluate the usefulness of each of the proposed functions, and the use of optimization methods will support the decision-making process of the business analyst. The model of such an organized decision-making process in project management is conveniently presented with Petri nets, which will allow visualizing sequential and parallel processes. Petri nets have proved to be a convenient tool for modeling the learning processes of people with special needs, maintenance, flows of an online store, basic cyber-physical attack models [12]-[14], etc.

The Petri net $C=(P, T, I, O)$ models the process of decision making in choosing additional functions (Fig. 2), where the set of positions $P=\{p_1, p_2, ..., p_8\}$, the set of transitions $T=\{t_1, t_2, t_3\}$; initial marking μ_0 is one chip in position p_1.

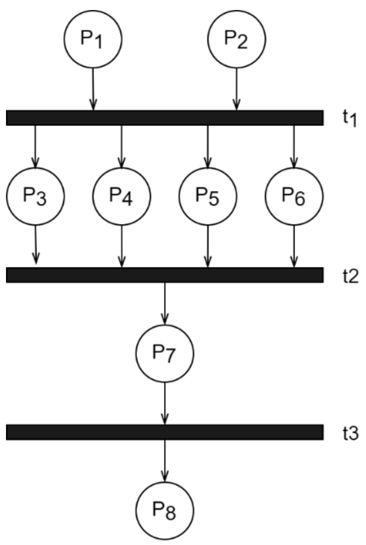

Figure 2. The process of decision making in choosing additional functions

Transitions in the given Petri net are events and are interpreted as processes (Table 1).

Table 1
Transitions in a model of decision making in choosing additional functions

Transitions	Meaning of transitions
t_1	Make an expert evaluation
t_2	Range the efficiency of the additional functions
t_3	Choose the best strategy of the realization of additional functions

Positions in the given Petri net can be interpreted as a condition of event occurrence (Table 2).

Table 2
Transitions in a model of decision making in choosing additional functions

Positions	Meaning of position
p_1	The alternatives of the additional functions
p_2	The criteria of efficiency evaluation of the additional functions
p_3	The assessments of the alternatives according to the criteria (by data scientists)
p_4	The assessments of the alternatives according to the criteria (by IT specialists)
p_5	The assessments of the alternatives according to the criteria (by state)
p_6	The assessments of the alternatives according to the criteria (by medics)
p_7	A set of alternative strategies of the realization of additional functions
p_8	A strategy of the realization of additional functions

In the process of expert evaluation of each of the additional functions that can improve basic IT, you can use, for example, the method of analytic hierarchy process (AHP). This method has been used for expert evaluation in various fields. For example, to model the delineation of artificial groundwater recharge potential regions, to model the selection of riparian protected area stretches [15]-[17].

In AHP, the evaluated alternatives are additional functions (mentioned before), and the evaluation criteria are the usefulness according to the assessments of experts (the representatives of the intersectoral cooperation process from Fig. 1). As a result of the application of the basic stages of AHP we will receive estimations of the usefulness of alternatives (at Fig. 3 there is an example of such estimations, where three alternatives are estimated by four experts). To obtain such estimations, the eigenvectors of each of the pairwise comparison matrices are multiplied by 10 and rounded to the integers.

7	2	4	3
2	6	5	3
1	2	1	4

Figure 3. Estimations of alternatives usefulness (using AHP)

To decide which of the alternatives should be realized, we propose to apply optimization methods, namely methods of game theory. Such a decision is made under conditions of uncertainty because even the most experienced experts do not always rationally estimate the magnitude of expected benefits or losses. Therefore, the problem presented by the matrix in Fig. 3 we propose to understand as a problem of game theory, namely games with nature, where decisions are made in conditions of uncertainty [18]. Several criteria have been developed for decision-making in conditions of uncertainty, which we will consider below.

3 Criteria for decision-making in conditions of uncertainty

In decision-making under uncertainty, the information required for decision-making is presented in the form of a matrix $Q = \|q_{ij}\|, i = 1,..., n, j = 1,..., m$ with rows $S = \{S_i\}, i = 1,...,n$ and columns $V = \{V_j\}, j = 1,...,m$. According to the analyzed example (Fig. 3), the rows S_i of such a matrix are the strategies of implementation of additional functions in information technology. The columns V_j of the matrix correspond to the conditions under which the corresponding additional functions will be implemented. Thus, the elements q_{ij} of the matrix are the numerical values of the usefulness of the corresponding strategy implementation (Fig. 4). We will consider the best strategy as one that is the most useful. The choice of such a strategy is complicated by a large number of alternatives and the need to take into account many conditions, which affect the usefulness of additional IT functions. Such conditions can be, for example, to promote the development of each particular industry, represented by the participant of the intersectoral cooperation process.

	V			
	V_1=<promotion of Data and Knowledge analysis>	V_2=<promotion of IT development>	V_3=<promotion of state development>	V_4=<promotion of medicine development>
S_1	7	2	4	3
S_2	2	6	5	3
S_3	1	2	1	4

Figure 4. Alternatives (strategies) of realization of additional functions

We will choose one of the alternatives according to different criteria *C*: the criteria of Laplace, Wald, Bayes, Hermeyer, Savage, Hurwitz, Khodg-Lehmann, as well as the criteria of extreme optimism, extreme pessimism, compromise criterion, and product criterion [19]-[24]. Each of the criteria has certain features and characteristics.

3.1 Wald criterion C_W

The criterion is considered a pessimistic criterion, because it focuses on the worst result, thus reducing the risks of decision-making. For each of the alternatives find the values of least usefulness, and choose the maximum of the values found. Wald criterion is formalized by formula (1):

$$C_W = \max_i \min_j q_{ij}, \ i = 1,...,n, \ j = 1,...,m. \quad (1)$$

Finding the best alternative by Wald's criterion for the task in Fig. 4, calculations are given in Fig. 5.

	V_1	V_2	V_3	V_4	$\min_j q_{ij}$
S_1	7	2	4	3	2
S_2	2	6	5	3	2
S_3	1	2	1	4	1

Figure 5. Calculations for decision-making according to the Wald criterion

According to the Wald criterion, it is advisable to choose alternatives S_1 or S_2.

3.2 The criterion of extreme optimism C_X

The criterion involves the choice of the alternative with the highest efficiency, the criterion does not take into account possible risks. To find the best alternative by this criterion, choose the maximum of the found maximum efficiency values for each alternative. The criterion of extreme optimism is formalized by formula (2):

$$C_X = \max_i \max_j q_{ij}, \ i = 1,...,n, \ j = 1,...,m. \quad (2)$$

Finding the best alternative by the criterion of extreme optimism for the task in Fig. 4, calculations are given in Fig. 6.

	V_1	V_2	V_3	V_4	$\max_j q_{ij}$
S_1	7	2	4	3	7
S_2	2	6	5	3	6
S_3	1	2	1	4	4

Figure 6. Calculations for decision-making according to the criterion of the extreme optimism

According to the criterion of extreme optimism, it is advisable to choose an alternative S_1.

3.3 The criterion of extreme pessimism C_P

The criterion involves choosing the alternative with the most pessimistic result. Only the worst possible result is taken into account. To do this, choose the minimum value among the smallest for each strategy, which is formalized by formula (3):

$$C_P = \min_i \min_j q_{ij}\,,\ i = 1,\dots,n,\ j = 1,\dots,m. \tag{3}$$

Finding the best alternative by criterion of extreme pessimism for the task in Fig. 4, calculations are given in Fig. 7. According to the criterion of extreme pessimism, it is advisable to choose an alternative S_3.

	V_1	V_2	V_3	V_4	$\min_j q_{ij}$
S_1	7	2	4	3	2
S_2	2	6	5	3	2
S_3	1	2	1	4	1

Figure 7. Calculations for decision-making according to the criterion of extreme pessimism

3.4 Product criterion C_M

This criterion for decision-making in conditions of uncertainty is mentioned in [19]. According to this criterion, the strategy with the largest product of efficiency values is chosen (all values of the efficiency must be positive). The criterion is formalized by formula (4):

$$C_M = \max_i \prod_{i=1}^{n} q_{ij}\,,\ i = 1,\dots,n,\ j = 1,\dots,m. \tag{4}$$

Finding the best alternative by product criterion for the task in Fig. 4, calculations are given in Fig. 8.

	V_1	V_2	V_3	V_4	$\prod_{i=1}^{n} q_{ij}$
S_1	7	2	4	3	168
S_2	2	6	5	3	180
S_3	1	2	1	4	8

Figure 8. Calculations for decision-making according to product criterion

According to the product criterion, it is advisable to choose an alternative S_2.

3.5 The criterion of compromise C_K

It is believed that the criterion makes it possible to choose a compromise strategy between optimistic and pessimistic. According to this criterion, the strategy with the highest value of the average between the maximum and minimum value of utility is selected. The criterion is formalized by formula (5):

$$C_K = \max_i \left[\frac{\max_j q_{ij} + \min_j q_{ij}}{2} \right], \; i = 1,...,n, \; j = 1,...,m. \qquad (5)$$

Finding the best alternative by the criterion of compromise for the task in Fig. 4, calculations are given in Fig. 9. According to the criterion of compromise, it is advisable to choose an alternative S_1.

	V_1	V_2	V_3	V_4	$\frac{\max_j q_{ij} + \min_j q_{ij}}{2}$
S_1	7	2	4	3	4,5
S_2	2	6	5	3	4,0
S_3	1	2	1	4	2,5

Figure 9. Calculations for decision-making according to the criterion of compromise

3.6 Hurwitz criterion C_H

The criterion makes it possible to indicate how close to the optimistic or pessimistic development the decision-maker is inclined. To do this, we use a coefficient λ called the coefficient of pessimism (realism), which is given within [0, 1]. In the case of λ = 1, the decision maker is prone to pessimism, and when λ = 1 to optimism. The difficulty of applying this criterion is in the need to determine the coefficient λ. The criterion is formalized by formula (6):

$$C_H = \max_i \left[\lambda \min_j q_{ij} + (1-\lambda) \max_j q_{ij} \right]_j, \; \lambda \in [0,1], i = 1,...,n, \; j = 1,...,m. \qquad (6)$$

Finding the best alternative by Hurwitz criterion for the task in Fig. 4, calculations are given in Fig. 10. According to the criterion of Hurwitz criterion, it is advisable to choose an alternative S_1.

	V_1	V_2	V_3	V_4	$\lambda \min_j q_{ij} + (1-\lambda) \max_j q_{ij}$ j
S_1	7	2	4	3	5,5
S_2	2	6	5	3	4,8
S_3	1	2	1	4	3,1

Figure 10. Calculations for decision-making according to Hurwitz criterion (with λ=0,3)

3.7 Laplace criterion C_L.

It is used in case of insufficient information about the event to be decided, and the probability of occurrence of each condition V_i will be considered the same. Then the optimal alternative is determined by the maximum average efficiency values (7).

$$C_L = \max_i \frac{1}{m} \sum_{j=1}^{m} q_{ij}, \; i = 1,...,n. \qquad (7)$$

Finding the best alternative by Laplace criterion for the task in Fig. 4, calculations are given in Fig. 11. According to the Laplace criterion, it is advisable to choose alternatives S_1 or S_2.

	V_1	V_2	V_3	V_4	$\frac{1}{4}\sum_{j=1}^{4} q_{ij}$
S_1	7	2	4	3	4
S_2	2	6	5	3	4
S_3	1	2	1	4	2

Figure 11. Calculations for decision-making according to Laplace criterion

3.8 Bayesian criterion C_B.

In contrast to the Laplace test, where the probabilities of conditions V_i are equal, the Bayesian criterion is based on the assumption that such probabilities are different. This fact often indicates that the conditions under which decisions are made are sufficiently studied, and it is possible to indicate the corresponding probabilities p_i of occurrence of each of the conditions, and $\sum_{j=1}^{m} p_j = 1$. According to the Bayesian criterion, the alternative for which the mathematical expectation is higher is also considered optimal. The criterion is formalized by formula (8):

$$C_B = \max_i \sum_{j=1}^{m} p_j q_{ij}\ ,\ i = 1,...,n,\ p_j \in [0,1],\ \sum_{j=1}^{m} p_j = 1\,. \tag{8}$$

Finding the best alternative by Wald's criterion for the task in Fig. 4, calculations are given in Fig. 12. Here, the vector of probabilities of occurrence of each of the conditions is *P=(0.2, 0.3, 0.1, 0.4).*

	V_1	V_2	V_3	V_4	$\sum_{j=1}^{m} p_j q_{ij}$
S_1	7	2	4	3	3,6
S_2	2	6	5	3	3,9
S_3	1	2	1	4	2,5

Figure 12. Calculations for decision-making according to Bayesian criterion

According to the criterion of extreme optimism, it is advisable to choose an alternative S_2.

3.9 Hermeyer criterion C_G.

As in the Bayesian criterion, the Hermeyer criterion takes into account the different probabilities of occurrence of each condition, however, the optimal alternative is chosen for which the minimum product of utility values on the probability of occurrence of the corresponding condition is the largest. The criterion is formalized by formula (9):

$$C_G = \max_i \min_j\ p_j q_{ij}\ ,\ i = 1,...,n,\ p_j \in [0,1],\ \sum_{j=1}^{m} p_j = 1\,. \tag{9}$$

Finding the best alternative by Hermeyer criterion for the task in Fig. 4, calculations are given in Fig. 13. Here, the vector of probabilities of occurrence of each of the conditions is *P=(0.2, 0.3, 0.1, 0.4).* According to Hermeyer criterion, it is advisable to choose alternatives S_1 or S_2.

	V_1	V_2	V_3	V_4	$\min_j\ p_j q_{ij}$
S_1	7	2	4	3	0,4
S_2	2	6	5	3	0,4
S_3	1	2	1	4	0,1

Figure 13. Calculations for decision-making according to Hermeyer criterion

3.10 Hodge-Lehmann criterion C_{HL}.

As in the Bayesian criterion, the Hodge-Lehmann criterion takes into account the different probabilities of occurrence of each condition. Also, as in the Hurwitz criterion, you need to set the value of the subjective variable *z*, which expresses the degree of confidence in the information about the conditions under which the decision is made, *z* is set within [0, 1]. The criterion is formalized by formula (10):

$$C_{HL} = \max_i \left(z\sum_{i=1}^{n} q_{ij} p_i + (1-z)\min_j q_{ij} \right),\ i = 1,...,n,\ j = 1,...,m. \quad (10)$$

It should be mentioned that in the case of *z*=0 (extreme distrust of the received information about the state of the system), the Hodge-Lehmann criterion becomes the Hermeyer criterion, and at *z*=1 (the information about the state of the system is reliable), the Hodge-Lehmann criterion becomes the Bayesian criterion.

Finding the best alternative by Hodge-Lehmann criterion for the task in Fig. 4, calculations are given in Fig. 14. Here, the vector of probabilities of occurrence of each of the conditions is *P=(0.2, 0.3, 0.1, 0.4), z=0.3.*

	V_1	V_2	V_3	V_4	$\sum_{i=1}^{n} q_{ij} p_i$	$\min_j p_j q_{ij}$	$z\sum_{i=1}^{n} q_{ij} p_i + (1-z)\min_j q_{ij}$
S_1	7	2	4	3	3,6	0,4	1,36
S_2	2	6	5	3	3,9	0,4	1,45
S_3	1	2	1	4	2,5	0,1	0,82

Figure 14. Calculations for decision-making according to Hodge-Lehmann criterion

According to Hodge-Lehmann criterion, it is advisable to choose an alternative S_2.

3.11 Savage criterion C_S.

The criterion should be used to protect the decision-maker from excessive losses. To make a decision, a risk matrix *R* is constructed on the basis of the initial condition matrix: the differences between the found maximum values in columns and the values of the initial matrix ($r_{ij} = \max_k q_{kj} - q_{kj}$) are put into the risk matrix. The criterion is formalized by formula (11):

$$C_S = \min_i \max_j r_{ij},\ i = 1,...,n,\ j = 1,...,m. \quad (11)$$

Finding the best alternative by Savage's criterion for the task in Fig. 4, calculations are given in Fig. 15. According to Savage's criterion, it is advisable to choose an alternative S_1.

	V_1	V_2	V_3	V_4
S_1	7	2	4	3
S_2	2	6	5	3
S_3	1	2	1	4
max	7	6	5	4

R=

				$\max_j r_{ij}$
0	4	1	1	4
5	0	0	1	5
6	4	4	0	6

Figure 15. Calculations for decision-making according to Savage's criterion

4 Discussion

According to the results of calculations based on decision-making criteria, alternative S_1 was the most useful according to four criteria (it is more than 36% of all criteria), according to three criteria -

alternative S_2 (over 27% of criteria), according to one criterion – alternative S_3 (over 9% of criteria), according to three criteria – alternatives S_1 or S_2 are equally useful (more than 27% of the criteria). Let's summarize the results of calculations graphically.

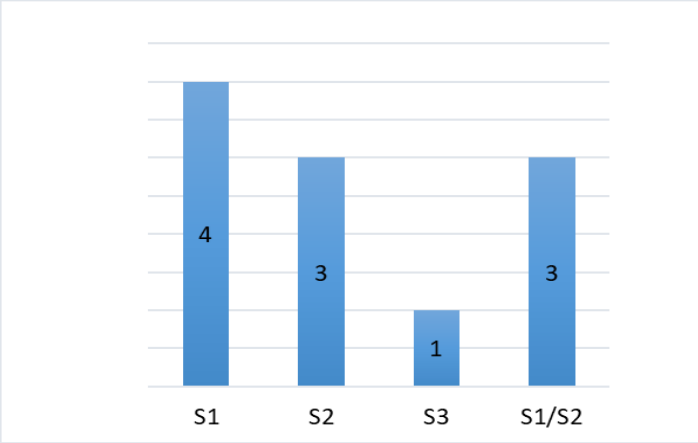

Figure 16. Visualization of the results of evaluating the feasibility of alternatives

5 Conclusions

To manage complex projects involving specialists from different fields, it is advisable to have a tool that will allow you to take into account the needs of such specialists. The proposed approach should be used by business analysts in the case of project management, which has some alternative scenarios, each of which is more or less useful in different conditions. In this case, the combination of AHP and decision-making under the uncertainty method will allow choosing the best alternative. The decision can be made from a pessimistic or optimistic point of view, and the ability to adjust certain parameters of the criteria (for example, in Hurwitz and Hodge-Lehmann criteria) will allow taking into account the views of experts involved in intersectoral cooperation.

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